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The Challenges of Managing Water for Wetland Ecology, Flood Mitigation and Agriculture in the Upper Lunan Water, an Intensive Arable Catchment in Scotland

Andrew Vinten and Iain D.M. Gunn

Abstract

The “Water for All” project has aimed to develop a multi-disciplinary science case for adaptive management through a Payment for Ecosystem Services (PES) scheme in the Lunan Water, a lowland catchment in Scotland. Management needs for high and low flows, standing water levels and flow routing to/from high nature value mesotrophic wetlands were appraised. A key part has been the development of a real time hydrological-hydraulic model of the upper Lunan Water as an aid to management and scenario analysis especially with respect to existing and potential hydraulic structures. This provides better working knowledge and forecast-based simulations of high or low flow situations for catchment management planners, farmers, riparian owners and other local stakeholders. Engagement with local users and residents has included surveying Willingness To Pay (WTP) for hydraulic management as a function of governance mechanisms, development of a catchment management group, and interviews and workshops with riparian and other land-users. The work has highlighted the joys and sorrows of seeking to develop a PES approach and lessons to be learnt in project management, promotion of multiple benefits, catchment-scale water governance and the vices and virtues of “benign neglect”.

Keywords: hydro-ecology, hydraulic modelling, Payment for Ecosystem Services, wetlands, water stakeholders

1. Introduction

Watershed or catchment management encompasses a complex tapestry of multi-stakeholder interests and water rights, cultural and historical norms, uncertainty of open system processes, and economic and environmental change [1, 2]. Moreover, the technical challenges to delivering across multiple objectives are significant. These include management of hydraulic structures, calibration of hydrological models of acceptable accuracy and precision, the need for real time or forecasted data streams and understanding of impacts of water management actions on ecosystems. A range of approaches has developed in recent years that aim to provide an integrated, consultative approach to natural resource management, among which

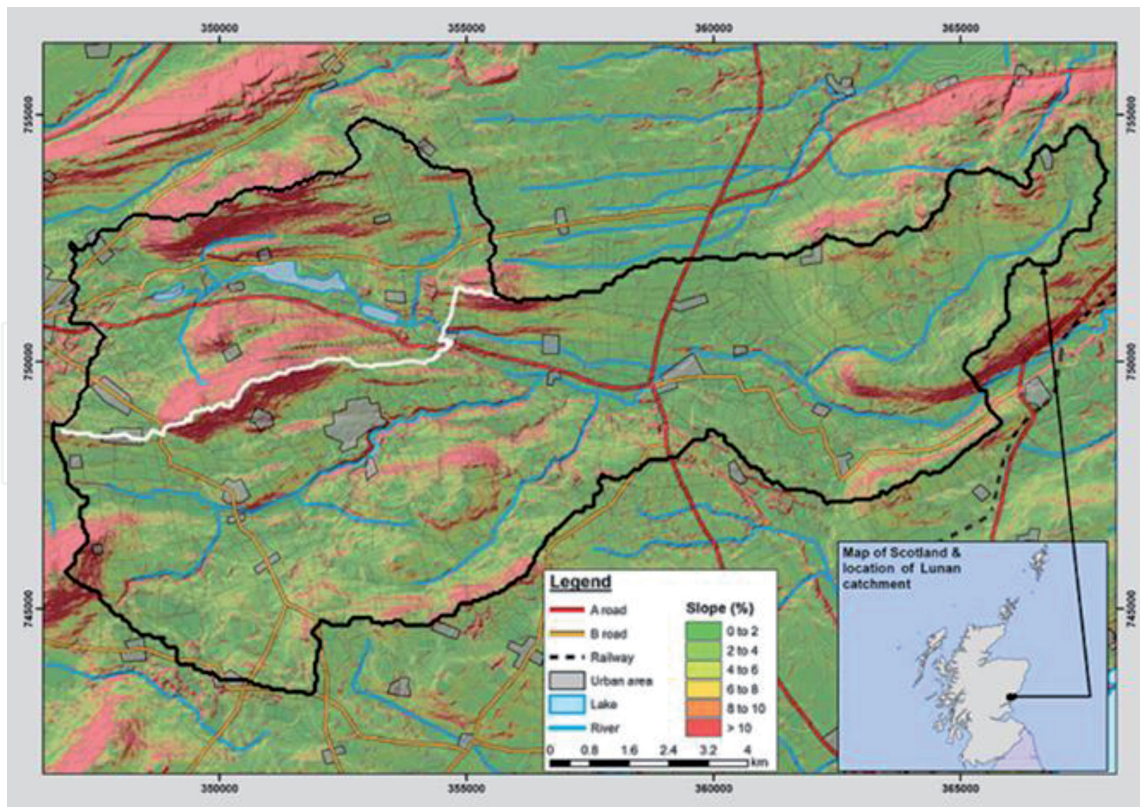


Figure 1.

Lunan water catchment. The upper catchment is delineated by the white line.

Payment for Ecosystem Services (PES) has emerged as a promising approach [3, 4]. PES schemes have been envisaged as an efficient way to ensure the provision of local public goods, such as water [5, 6]. Such schemes have the potential to increase the availability of ecosystem services for beneficiaries, whilst compensating the providers of such services. Examples of successful PES schemes with a focus on water include the Vittel water catchment area in France [7] and the “Upstream Thinking” scheme in SW England [5]. However, some aspects of catchment water management, such as the widely distributed and ill-defined benefits, and legacy issues, can undermine local participation and willingness to pay [3, 7].

This chapter outlines the evolution of an engineered water management strategy (“Water for All”) for the Lunan Water catchment area, Angus, Scotland (see **Figure 1**). The project originally envisioned alleviation of winter flooding in the upper catchment, summer low flows and water shortages in the lower catchment, and nutrient/sediment pollution in wetland areas, to be managed as a PES scheme through local management and funding. The key engineered element was the introduction of remotely managed hydraulic controls (e.g. a tilting weir) to deliver the envisioned benefits.

Integrated analysis was made up of three main components:

- Hydrological analysis focused on deriving rainfall-runoff relationships for inflowing streams and a hydraulic model of the main channels and standing waters. This allowed simulation of upstream water levels and partitioning of flows as a function of existing or proposed management of hydraulic structures. It made use of long-term monitoring and survey data and the hydraulic modelling tool HECRAS 5.0.7;
- Ecological analysis considered the vegetation characteristics of the wetland using the UK National Vegetation Classification scheme [8], and the likely

mixing behaviour of water from the river with other sources contributing to the wetlands, using End Member Mixing Analysis [9];

- Governance and stakeholder analysis focused on regular engagement through a stakeholder group (Lunan Catchment Management Group, which was set up at the start of the project in 2017), a survey of Willingness to Pay (WTP) for the tilting weir option, and interviews discussing the uncertainties and governance gaps that might impede implementation.

2. Ecosystem services provision potentially influenced by water management

At the start of the “Water for All” project, a workshop was run which compared the Lunan Water with the River Leven, another lowland catchment in eastern Scotland. Eight main elements of Ecosystem Services Provision that could be affected by water management in the two catchments were identified. These are summarised in **Table 1**. Of these, those marked as having a high potential for influence in the Lunan Water became the focus of attention for that catchment. A separate project [10] explored the potential of flushing for control of algal blooms in Loch Leven, on the River Leven, using the Lake algal model PROTECH [11].

The key risk factors considered for improved management were:

- Flood risk mitigation. A tilting weir, as a lateral structure on the common lade, could be used to modify flows from the upstream lakes to achieve a lower base level in the lakes prior to winter high flows, and provide managed release. Dredging of the mill lade might also be used to achieve this, but with less flexibility and greater potential for adverse impact;
- Risk of eutrophication of floodplain wetlands. Phosphorus, nitrogen and sediment discharge from the lakes displayed strong annual variation. Inflow of sediment/nutrient-rich waters can lead to loss of biodiversity in wetlands [12].

Influences of hydraulic management on Ecosystem Service Provision	Importance for two catchments in E. Scotland	
	Lunan Water	River Leven
a. The ecological response of changing water levels in wetlands associated with the standing waters.	H	M
b. Potential for management of water quality and pollutant loading into wetlands	H	M
c. The impact of flushing regimes, as determined by hydraulic structures, on aquatic ecology.	M	H
d. The management of fish passage and influence on ecology of fish	M	M
e. Opportunities and barriers for ecotourism	M	H
f. Governance needs for water level management.	M	H
g. Opportunities for hydro schemes	L	M
h. Upstream and downstream flood risk, as influenced by hydraulic management and other factors	H	M

Table 1.
Influences of hydraulic management on ecosystem service provision for two catchments in eastern Scotland.
H = high, M = medium, L = low.

A tilting weir, as a lateral structure on the common lade, could help divert these sediment/nutrient rich waters away from floodplain wetlands at key times;

- Risk of low flows. This could cause damage to ecological status of the river and economic impact to downstream irrigators. An in-line tilting weir at the lake outlet to the common lade could act as a penning structure to facilitate retention of water in early summer in the lakes, to provide water for abstraction and maintain low flows. This element of the analysis was considered in detail elsewhere [13].

3. Hydrological analysis

The surface water sub-catchment areas for the upper Lunan Water have been separated, for water balance purposes, into the areas used for hydraulic modelling, which are shown in **Figure 2**. The areas of each of these sub-catchments were used to scale measured and modelled flows from monitored sub-catchments where water flow and water quality monitoring occurred. These are the Balgavies Burn sub-catchment, at Westerton (area = 4.4 km²), which generates real time stage and flow data and the Baldardo Burn sub-catchment at Wemyss (area = 2.4 km²), which generates water level data.

The “Water for All” project focused on the outlet zone of Balgavies Loch (**Figure 3**), where the Lunan Water discharges into a partially confined common channel (lade). This lade controls water delivery to a mill or returning to the river, controlled by an existing engineered gated weir, and water also flows from the river into its lateral floodplain wetlands (Chapel Mires) via a non-engineered spillage zone, which replaced a now-blocked engineered spillway in the 1970’s. The ecological value of these wetlands may be vulnerable due to ingress of sediment and

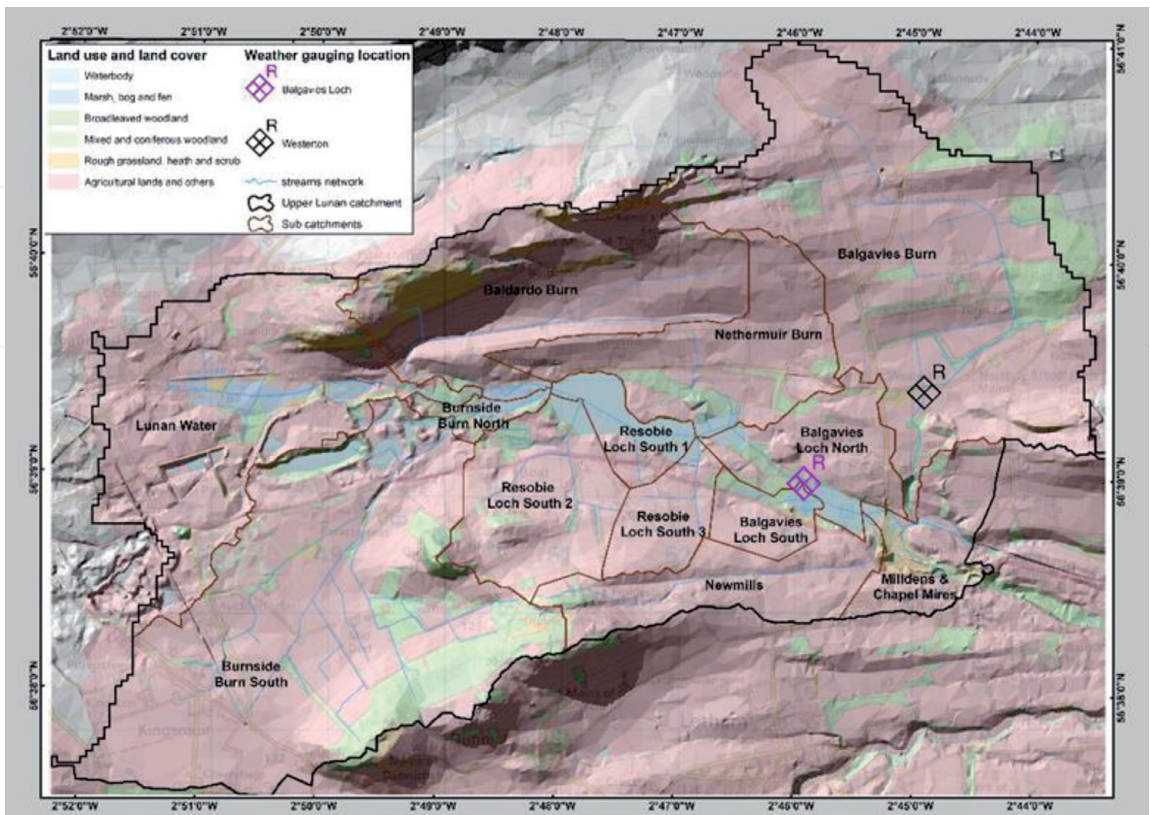


Figure 2.
Sub-catchments of upper Lunan water used in hydrological-hydraulic modelling.

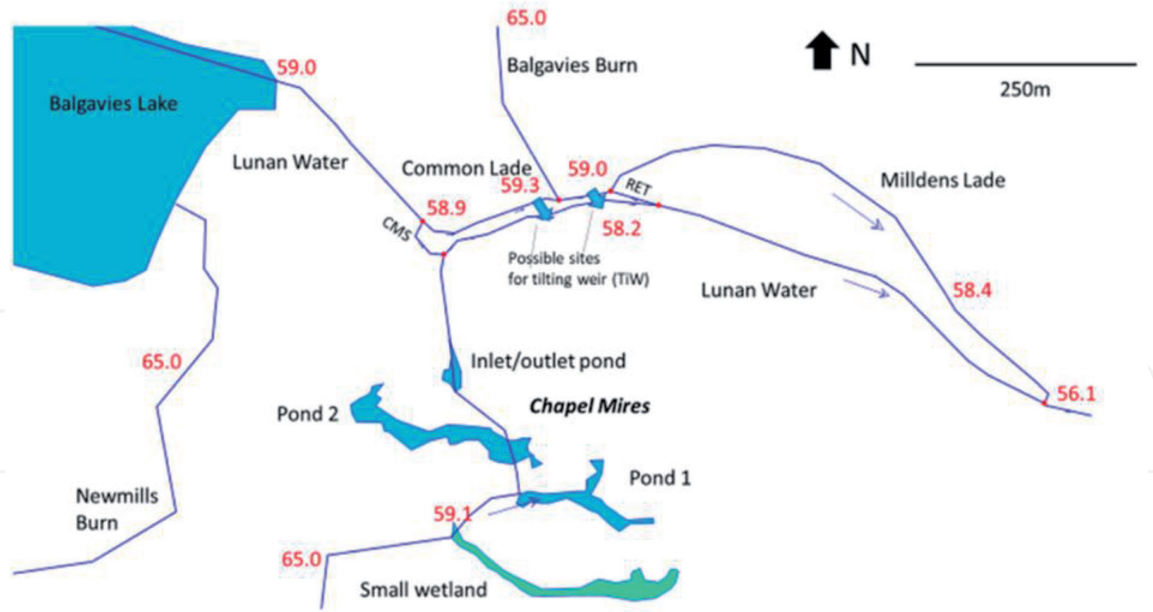


Figure 3.
Outlet structures of Balgavies loch to Lunan water. Bed levels shown in red in m above sea level. RET = return gate from common lade to Lunan water; CMS = existing chapel mires spillway; TIW1, TIW2 = possible sites for installation of tilting weir to manage flow routing and upstream water levels. Figures in red are elevation of bed level of stream above sea level in metres.

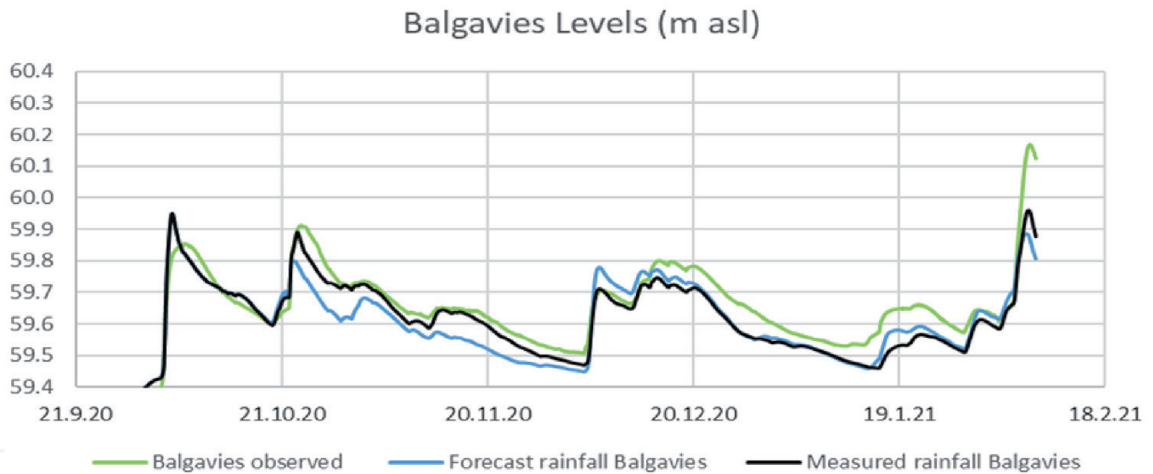


Figure 4.
Observed water levels in Balgavies loch over Oct 2020-Feb 2021 compared with results of simulations using the hydrological model with two alternative assumptions: a. using observed rainfall b. using rainfall from the 1d forecast on a 2x2km2 grid, updated daily from the UK meteorological office.

nutrients from the river [12, 14]. Hydro-ecological assessment involved developing a model of the upper Lunan Water and the operation of this outlet zone. The aim of the modelling is to generate a time series of historic, real-time and forecast based surface water and ground water flows and water levels in the upper Lunan Water catchment, whose area is defined by the surface water outlet at Milldens bridge (Grid Reference NO 354526 750566). These could then be used to provide triggers or other guidance for hydraulic management. This model is now running in a real time and forecasting mode.¹

The hydrological-hydraulic model has the capability to simulate water levels in the upper Lunan Water lakes as illustrated in **Figure 4**, and flow routing between the Common Lade and the Lunan Water.

¹ <https://www.hutton.ac.uk/research/projects/payments-ecosystem-services-lessons#waterforall>

The model calibration provided the basis for some level of certainty about the impact of existing and potential hydraulic management. The scenario analysis pointed to the rather low impact of installation of a tilting weir on upstream water levels, whether this were to be installed either above or below the confluence of the Balgavies Burn and the Common Lade. However, it also pointed to a larger impact on water levels if dredging/vegetation management or other interventions that affect the Manning roughness coefficient downstream of Balgavies Loch are undertaken, in conjunction with tilting weir installation. It also shows that flow routing could be significantly impacted by a tilting weir, or by reinstatement of the blocked spillway downstream of the current spillway (see **Figure 3**), especially if combined with local dredging and/or vegetation management.

4. Ecological analysis

Rescobie and Balgavies Lochs, covering 1.78 km², support over 60 species of breeding birds and with their surrounds form a Site of Special Scientific Interest (SSSI). There are many aquatic species such as *Menyanthes trifoliata* (Bogbean) and *Utricularia australis* agg. (Bladderwort) that occur in shallow water and any significant change in water levels could affect them. In the area south of the Lunan Water (Chapel Mires – see **Figures 5** and **6**) there is a complex mosaic of open water, willow scrub and sedge-dominated fen vegetation including *Carex rostrata*-*Calliergon* mire, *Filipendula ulmaria*–*Angelica sylvestris* mire, *Phalaris* swamp, *Carex rostrata* swamp and *Carex rostrata*–*Equisetum fluviatile* sub-community occupying the lower lying areas. This has led to this area also being included in the Rescobie and Balgavies Lochs SSSI. The Nationally Scarce *Cicuta virosa* (Cowbane) and *Lysimachia thyrsiflora* (Tufted Loosestrife), could be threatened by changes in water levels or the input of sediment/nutrients as shown by [12].

Water sampling around Chapel Mires compared with the outlet of the Lunan Water at Bagavies Loch, and End Member Mixing Analysis (EMMA) confirmed the vegetation analysis and helped confirm the need to manage pollutant rich water inflow, especially if storm waters threaten the southern and eastern parts of the wetland, which are more pristine (see **Figure 7**).



Figure 5. Chapel mires viewed from the SW. The line of the Lunan water is the trees between the arable (yellow) and grassland (green) field in the middle distance.

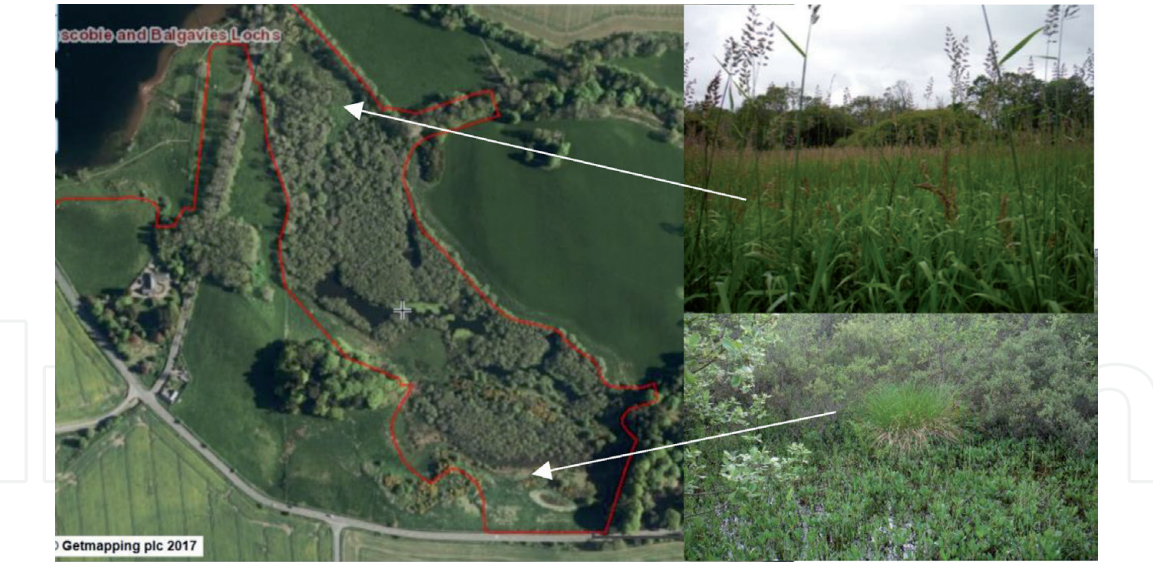


Figure 6.
Aerial view of chapel mires (red line shows SSSI boundary) and gradient of vegetation from (top right) *Phalaris arundinacea* (reed canary-grass) and *Sparganium erectum* (branched bur-reed) rich (sediment tolerant) to (bottom right) *Carex rostrata* (bottle sedge) and *Menyanthes trifoliata* (Bogbean) rich (sediment intolerant) associations with distance from the Lunan water (located on northern boundary).

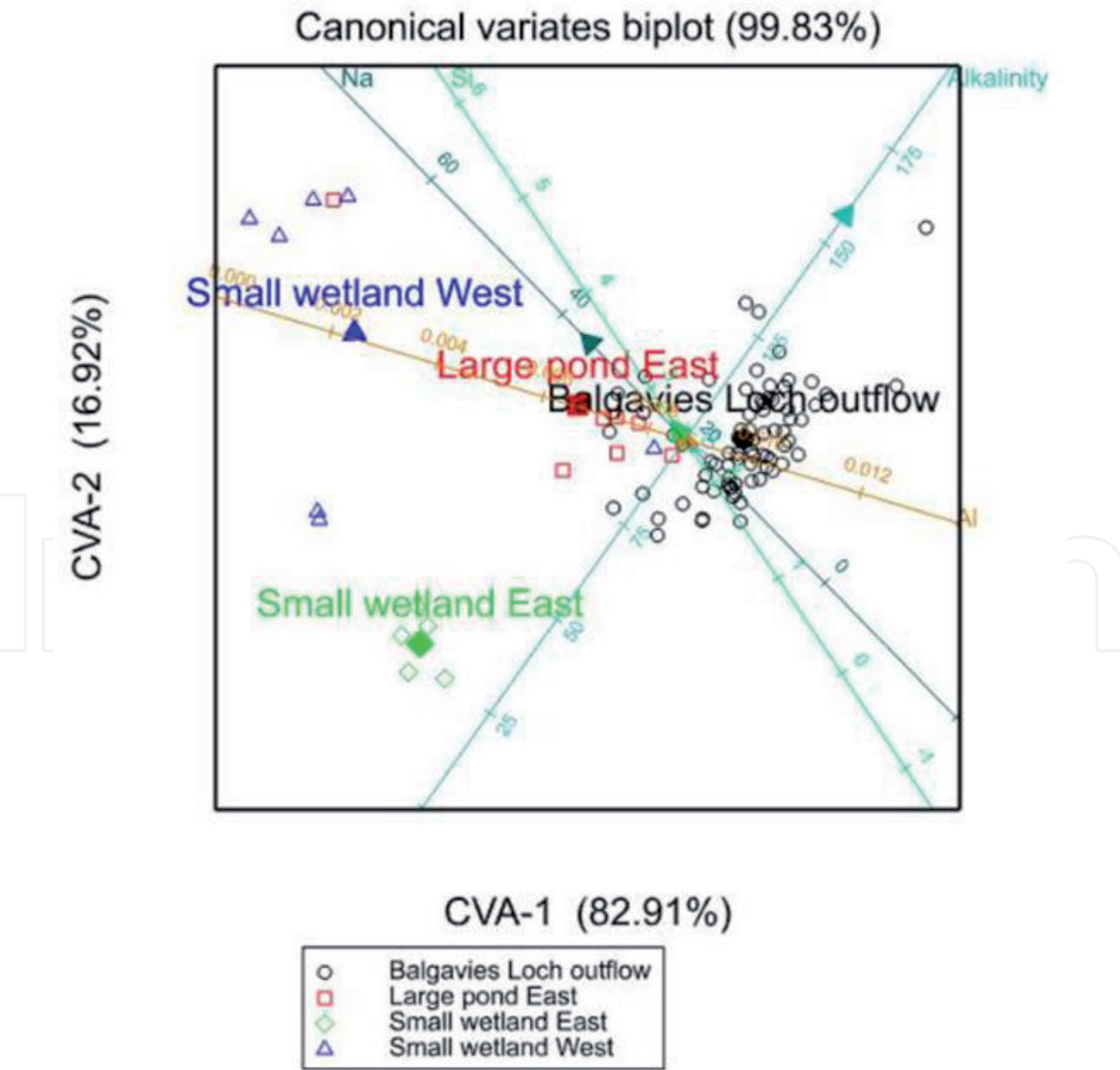


Figure 7.
Canonical variates biplot of water chemistry for the wetlands of chapel mires and the outflow of Balgavies loch, showing that the wetlands on the south eastern fringe of chapel mires are geochemically distinct.

5. Analysis of stakeholder engagement

Figure 8 summarises the conceptual framework for engaging with stakeholders.

Detailed analyses of the results of a Willingness to Pay survey and interviews with riparian, other landowners and government agency stakeholders are reported elsewhere. Reports of the Lunan Catchment Management Group meetings can be found at the project website (see Footnote 1 above).

The following list summarises some key findings of this engagement process:

1. It is challenging to demonstrate technical feasibility

The development and validation of the model to assess the impact of management scenarios on water levels and flow routing was a complex and time-consuming process. The project was set up with both technical and social science goals, which needed to run in parallel, yet each of which had uncertain outcomes;

2. Predicted benefits are quite thinly spread across users

The multiple benefits of the scheme for flood risk, low flow risk, and ecological conservation was seen as a selling point for a Payment for Ecosystem Services scheme, but in practice it diluted the beneficial impact for each stakeholder and made the technical justification of the scheme based on robust evidence, more challenging;

3. The strongest concerns are for long-term management and legal issues

The catchment has historically supported a series of working water mills for grain processing, and there is still historical memory of water disputes arising from these. While none of these mills are now operating commercially, there is still a recognition that active water management has the potential for dispute and legal challenge. A “benign neglect” approach, based on passive management, is therefore favoured by some. Governance systems to deal with such issues are generally weak in Scotland;

4. Among those in favour of “Water for All”, there were no clear champions

The multiple benefits aspects of the proposed scheme has meant that it has proved difficult to identify a single agency with sufficient interest to promote proposals. This has changed recently, with a more unified strategy to promote the benefits of the scheme for wetland ecological conservation;

5. The need to dedicate time and energy to pursuing approval for installation and management after installation

The costs of demonstrating the proof-of-concept elements of the research project have detracted from the pursuit of management and governance planning post-installation and have led to adoption of a proposal that is more passive (reinstatement of blocked spillway) rather than active (management of a remotely operated tilting weir);

6. Insufficient or doubtful benefit to stakeholders

The need for co-ordinated long-term planning and the existence of likely trade-offs (e.g. between up- and downstream interests; between wetland ecology and farming; between fisheries and irrigators; around issues of access to the environment) has led to some stakeholders considering the work required to

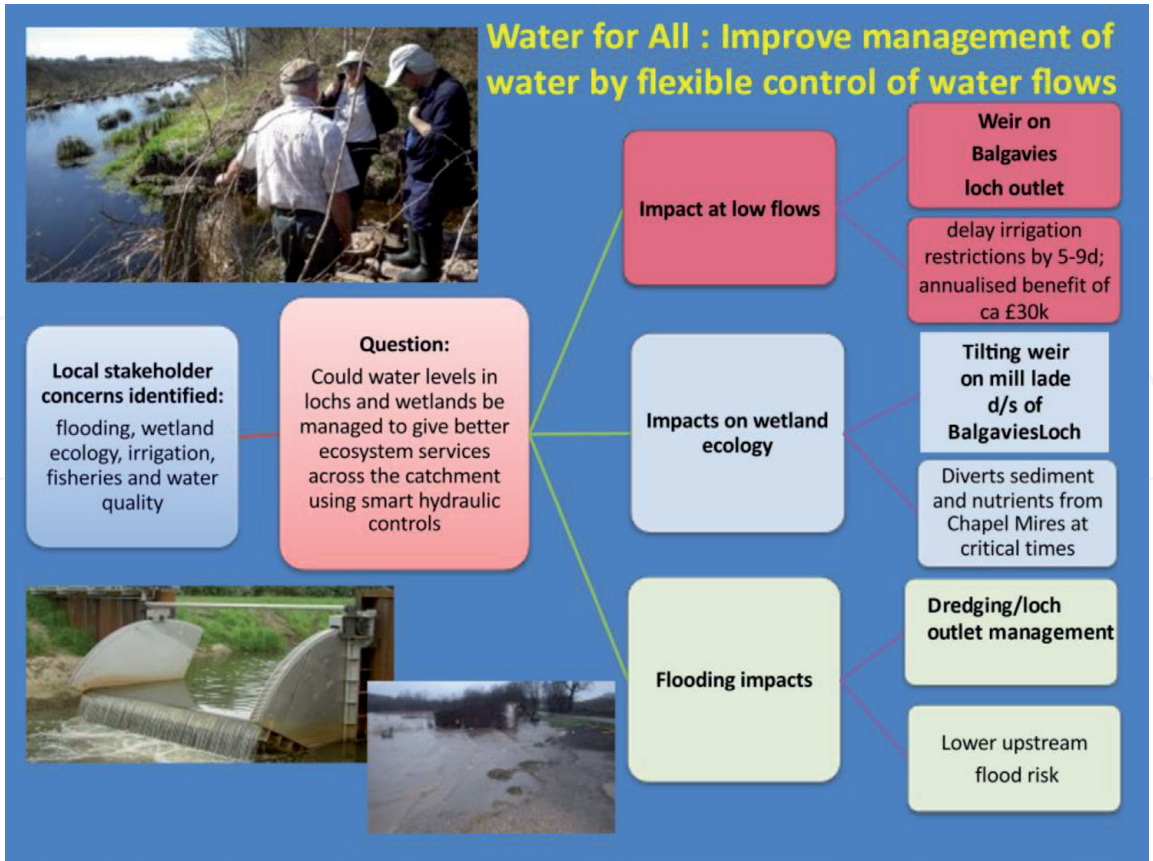


Figure 8.
Conceptual framework for engagement with agencies, land users and other stakeholders.

achieve benefits is incommensurate. Few stakeholders have a comprehensive overview of benefits;

7. Lack of precedence

Except on larger, well regulated catchments with strong fisheries, hydroelectric, water supply, navigation, abstraction or sewerage interests, such as the Tay, the Tweed, the Clyde, the Dee and the Forth, or on those designated for Priority Action under the Water Framework Directive, there is little precedence for local Catchment Management Groups and for use of hydraulic structures for integrated management;

8. Need for drainage boards in Scotland?

Recent legal precedent elsewhere has led to a highlighting of the potential for drainage boards to be established in Scotland. The Pow of Inchaffray Drainage Board (River Earn catchment) and the North Glasgow Drainage scheme (River Kelvin and Scottish Union Canal) are recent examples where legally binding governance schemes have been established. The River Leven is also regulated by sluice gates on Loch Leven, but the governance of these gates is based on anachronistic rules developed in the context of obsolete industries downstream.

6. Deliberation and adaptation of objectives

In any integrated water management project of this kind, it is also vital to respond adaptively to stakeholder issues and barriers to implementation [15]. This

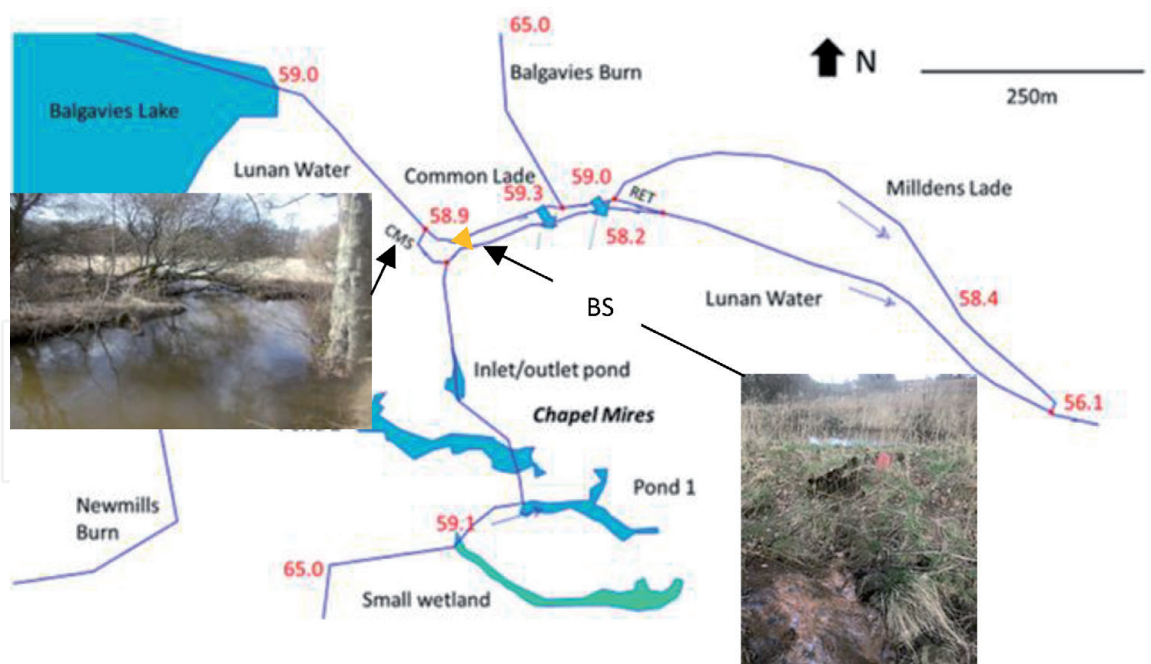


Figure 9.

Position of existing spillway separating the Lunan water from the common lade (CMS) and blocked spillway (BS), which was agreed with riparian owners and the Lunan catchment management group could be re-instated.

project was one of a group of case studies that considered adaptive catchment management across Scotland².

Having considered the concerns listed above, a modified proposal was tabled to the Lunan Catchment Management Group and to riparian owners. This focused on re-instating a blocked spillway downstream of the existing spillway where the river and Common Lade separate (CMS in **Figures 3 and 9**). This blockage had been installed in the 1970's, to enhance the flow of water to the mill lade to feed a recently reinstated historic water mill. Modelling of scenarios of hydraulic management showed that this approach would provide one of the key benefits of the original scheme, namely the protection of Chapel Mires wetland ecology from sediment from Newmills Burn during peak runoff events. It would have a more passive approach to management and be in keeping with current river restoration policies aiming at returning to natural flow regimes, where possible. The modified proposals were agreed in principle by the local interest groups, opening the way for solicitation of funding for the re-instatement works required.

7. Conclusions

In any project of this kind, it is vital to respond adaptively to stakeholder issues and barriers to implementation. This chapter highlights key elements of an “action research” project to underpin Scottish Government science policy for sustainable management of water resources in Scotland. The paradigm of Payment for Ecosystem Services underpinned the approach taken and the aspiration was to see a pilot PES scheme developed and assessed within the original 5-year time. However, the combined challenges of demonstrating the technical benefits, adaptive response to stakeholder concerns and lack of governance structures for water resources

² https://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/RESAS_srp143_aD1_ReportOnRelevantAdaptiveManagementApproachesForScotland_v0.8Final.pdf

management at a catchment scale have slowed the process. The lessons learnt include:

1. Project management. Where technical challenges need to be met (i.e. development of a plausible hydraulic model), these may need to take precedence in the early part of project delivery, notwithstanding the need for co-operative development of project objectives;
2. Multiple Benefits. While the delivery of multiple benefits is a widely held aspiration, it may lead to a lack of championing of a proposal across different interest groups;
3. Governance. Weak, non-existent, vested or anachronistic governance mechanisms can be a barrier to implementation of water management projects, even at a relatively local scale. They may actually be more challenging at a small scale and on lower priority catchments where less leverage of regulation or funding occurs;
4. Passive vs. active water management. There is a tendency to descend to the lowest common denominator of “benign neglect” in management of water at a catchment scale. Cultural norms and perceptions tend to favour the status quo. It may be that such an approach is beneficial to overall ecosystem service delivery when economic as well as public goods are considered. However, any potential negative consequences of a new structure or intervention tend to be weighted more heavily in decision-making than the known negative consequences of the systems that we already have;
5. A way forward does now exist that has potential to deliver improvement of ecosystem services, but the payments mechanisms for works and ongoing monitoring and management are yet to be resolved.

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Conflict of interest

The authors declare no conflict of interest.

Notes/Thanks/Other declarations

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Author details

Andrew Vinten^{1*} and Iain D.M. Gunn²

1 James Hutton Institute, Aberdeen, UK

2 UK Centre for Ecology and Hydrology, Edinburgh, UK

*Address all correspondence to: andy.vinten@hutton.ac.uk

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